

*KEY PECKING DURING EXTINCTION AFTER  
INTERMITTENT OR CONTINUOUS REINFORCEMENT AS  
A FUNCTION OF THE NUMBER OF REINFORCERS  
DELIVERED DURING TRAINING*

TROY J. ZARCONI, MARC N. BRANCH,  
CHRISTINE E. HUGHES, AND HENRY S. PENNYPACKER

UNIVERSITY OF FLORIDA

Key pecking by 7 pigeons was established and maintained on a multiple variable-ratio variable-ratio (VR) schedule of food presentation. The schedule in one of the components was then changed to fixed-ratio (FR) 1 for a predetermined number of reinforcers. Both components were then changed to extinction (i.e., multiple extinction, extinction). This sequence was repeated a different number of times for each pigeon to determine the relation between the number of reinforcers delivered during each component of the multiple VR FR 1 schedule and the number of responses during extinction. For most pigeons, there were fewer responses during extinction in the presence of a stimulus recently correlated with FR 1, regardless of the number of reinforcers received. The ratio of the total responses in extinction in the former VR component to the total responses in the former FR 1 component increased as the number of reinforcers delivered during each component of the multiple schedule increased. Within-subject replications of the partial-reinforcement extinction effect generally occurred, and there were no overall reductions in the number of responses in extinction with repeated exposures to extinction.

*Key words:* partial-reinforcement extinction effect, continuous reinforcement, variable-ratio reinforcement, extinction, behavioral momentum, key peck, pigeons

Identifying the variables that determine when an animal will give up or continue to respond for a particular commodity is important in the understanding of environmental conditions common to most living organisms. Most, if not all, organisms live in a world in which access to food, water, sexual partners, and other commodities does not always occur reliably. Animals that continue to respond when commodities do not occur reliably may have a selective advantage compared to organisms that give up, if persistence eventually leads to obtaining the commodity. Persistent responding when a commodity has been used

up (e.g., overfishing a small pond) could be detrimental if it prevented the organism from going on to more profitable activities (e.g., searching a bush for berries). Any general theory of behavior has to be able to deal with the persistence of behavior when contingencies for that behavior have changed (Jenkins & Stanley, 1950), especially when that change is to extinction.

The investigation of behavior that is no longer reinforced became a commonly used tool in the testing and refinement of early theories of behavior. The usual method of examining the effects of different schedules of reinforcement on persistence involved between-groups comparisons (see Jenkins & Stanley, 1950, for a review). Separate groups of subjects were exposed to different schedules of reinforcement followed by the withdrawal of reinforcement. The usual result is a robust effect called the partial-reinforcement extinction effect (PREE), which describes the greater persistence in responding during extinction (EXT) following a history of intermittent reinforcement compared to reinforcement of every response (fixed-ratio [FR] 1). Despite the consistency of the results produced by the between-groups design, the question remained regarding whether this phenomenon

---

Research supported by USPHS Grant DA 04074. Data from both extinction curves from Pigeon 2374 and the first extinction curve from Pigeon 3180 were presented in a master's thesis by the first author. Portions of this paper were presented at the Annual meeting of the Association for Behavior Analysis: International in Atlanta, May 1991. This experiment was conducted at the University of Florida as part of the first author's doctoral research program under the supervision of the second and fourth authors. We thank Peg Gratton for her assistance in the completion of this experiment. The third author is now at the University of North Carolina–Chapel Hill.

Reprints may be obtained from Troy J. Zarcone, Johns Hopkins Medical Institutions, Behavioral Biology Research Center, Hopkins Bayview Research Campus, 5510 Nathan Shock Drive Suite 3000, Baltimore, Maryland 21224-6823 (E-mail: Zarcone@bpru.uucp.jhu.edu).

was reflective of a process observable in individual organisms, a question best answered by attempting to replicate the PREE using a within-subject experimental design.

In a within-subject experiment designed to examine the PREE, each subject is trained on a continuous and intermittent reinforcement schedule and then is exposed to extinction. Each schedule of reinforcement can be presented at different times and in the presence of different discriminative stimuli (i.e., as components of a multiple schedule). During extinction the different discriminative stimuli continue to be presented at different times, but without reinforcement. Many attempts at generating a within-subject PREE have produced reversed PREEs, that is, more persistent responding after FR 1 than after intermittent reinforcement (e.g., Adams, Nemeth, & Pavlik, 1982; Nevin, Mandell, & Atak, 1983; Pavlik & Carlton, 1965; Pavlik, Carlton, Lehr, & Hendrickson, 1967). One possible reason for the reversed PREEs may be that within-subject procedures usually have maintained equal component durations for the FR 1 and intermittent reinforcement schedules. This arrangement results in fewer reinforcer presentations under the intermittent reinforcement schedule than under the FR 1 schedule. In support of this view, previous parametric analyses have shown that the number of responses made during extinction increases with increases in the number of reinforcers during training in both simple schedules (Jenkins, 1962; Perin, 1942; Williams, 1938; Wilson, 1954) and multiple schedules (Hearst, 1961). The purpose of the present experiment was to investigate the effects of using a within-subject procedure that equated the number of reinforcers presented by the intermittent and FR 1 reinforcement schedules prior to extinction.

An additional purpose of this experiment was to determine the extent to which the implementation of FR 1 after intermittent reinforcement would reduce the number of responses emitted during extinction. If intermittent reinforcement produces more persistent responding during subsequent extinction than does FR 1, presentation of FR 1 after intermittent reinforcement might be expected to reduce the degree of persistence (Theios, 1962). The effects of FR 1 on behavior that has been previously maintained

on intermittent reinforcement have been mixed. Many early experiments showed no reductions in persistence with the interpolation of FR 1 (Jenkins, 1962; Likely, 1958; Quartermain & Vaughan, 1961; Sutherland, Mackintosh, & Wolfe, 1965; Theios, 1962), but later experiments showed reductions (Dyal & Sytsma, 1976; Stalling, Moreland, Merrill, & Scotti, 1981). One possible explanation for the different results may lie in the training procedures. The earlier experiments involved training two groups of subjects with intermittent reinforcement. The group that received only intermittent reinforcement was then exposed to extinction. The group that received the interpolated FR 1 received additional reinforcement before extinction, resulting in more reinforcer presentations for the intermittent-plus-FR 1 group. The later experiments that showed a reduction in persistence after FR 1 training included continuing exposure of the intermittent-reinforcement group to intermittent reinforcement while exposing the other group to FR 1 reinforcement. The importance of the number of reinforcer presentations is further suggested by the results of a reanalysis of data reported by Jenkins (1962, Experiment 2). Jenkins found no statistically significant difference between a group that received only intermittent reinforcement and a group that received intermittent reinforcement plus additional FR 1. Our post hoc comparison of groups in this same experiment with an equal number of reinforcer presentations, however, showed that interpolated FR 1 reduced the responding in extinction. Again, the number of reinforcer presentations during training seemed to play an important role in the persistence of responding during extinction, and this variable may account for some of the discrepancies found in the PREE literature.

## METHOD

### *Subjects*

Seven adult male experimentally naive White Carneau pigeons (*Columba livia*) were housed individually in a colony room (16:8 hr light/dark). They had continuous access to vitamin-enriched water and health grit. Pigeons 2374, 3180, and 3519 started the experiment at 80% of their free-feeding

weights, but were later reduced to 70% to increase stability of responding (see below). Pigeons 2822, 2842, 2875, and 2880 were maintained at 70% of their free-feeding weights throughout the experiment. Each bird was fed mixed grain after the experimental session as necessary to maintain the desired body weight.

#### Apparatus

An operant conditioning chamber for pigeons (Lehigh Valley Electronics Model 1519c) with workspace dimensions of 35.5 cm by 30.5 cm by 35.5 cm was used. The chamber was fitted with a three-key display board (Model 132-02). Three response keys, 2.5 cm in diameter, were located 5.6 cm from each other and 23 cm from the chamber floor in a horizontal row on the display wall. Only the center key was used in the experiment. A key peck with a force greater than 0.18 N started a 70-ms tone from a Sonalert® (Model SC628) and was counted as a response. The Sonalert® was located behind the front wall, 2.0 cm from the floor. The center key could be transilluminated from the rear by a white, green, or red light. The left key was dark and inoperable, and the right key was replaced with an aluminum plate. The chamber was illuminated by a 1.2-W bulb (houcelight) 5.5 cm above the center key.

During the 3-s operations of the food hopper, pigeons gained access to mixed grain (0.5 milo, 0.4 buckwheat, 0.1 hemp).<sup>1</sup> The opening to the food hopper was 5.7 by 5.2 cm and was located 9.0 cm below the center key. The inside of the food hopper was illuminated by a 1.2-W bulb. During food presentations the keylight and houselight were turned off.

The chamber was kept in a room in which white noise was present continuously. A custom-built computer, operated under the EC Basic control system (Walter & Palya, 1984), programmed contingencies, collected data, and interfaced with an IBM®-compatible computer in an adjacent room. A Gerbrands (Model C-3) cumulative response recorder was also used to monitor responding.

<sup>1</sup> To decrease variability in responding for Pigeon 3180, the hopper duration was shortened to 2.5 s to reduce possible satiation effects towards the end of daily sessions. This change in the hopper duration occurred before the first extinction series.

Table 1

Schedules, keylight color assignments, and number of components per session.

Pigeon	Green keylight component	Red keylight component	Number of components per session
2822	VR 100	VR 100 or FR 1	8
2875-1	VR 100	VR 100 or FR 1	8
2	VR 25	VR 25 or FR 1	8
3	VR 25	VR 25 or FR 1	8
2842	VR 50	VR 50 or FR 1	8
3519	VR 50	VR 50 or FR 1	10
2374	VR 100	VR 100 or FR 1	10
3180	VR 100 or FR 1	VR 100	10
2880	VR 50 or FR 1	VR 50	8

*Note.* For Pigeon 2875 different VR schedules were used between the first extinction series and the extinction series that followed (i.e., 2 and 3).

#### Procedure

*Key-peck shaping and schedule fading.* Each pigeon was placed in the chamber for at least two 30-min adaptation sessions in which the houselight was on and no behavioral contingencies were programmed. Magazine training followed until pigeons reliably approached and ate from the hopper with short latencies after it was raised. Key pecking was shaped by differentially reinforcing successive approximations to the final response. The keylight was white during this training. After key pecking had been maintained for two sessions of FR 1 (40 reinforcers per session), the schedule was changed to a multiple FR 1 (green keylight) FR 1 (red keylight) schedule. Throughout all conditions in which reinforcement was available, components alternated after every fifth reinforcer presentation and were separated from each other by a 1-min timeout (houselights and keylights turned off). The starting component of the multiple schedule was determined each day by a Gellermann (1933) series (green, red, green, green, red, green, red, red; repeats). Sessions ended after 8 or 10 components (see Table 1). The response requirement was increased gradually until key pecking was maintained on two equal variable-ratio (VR) schedules. Table 1 shows the terminal VR schedules for each pigeon. The VR schedules were constructed by randomly selecting, with-

out replacement, values from a list of 25 numbers ranging from 1 to twice the value of the VR schedule (e.g., VR 100: 1, 12, 19, 25, 37, 44, 50, 62, 69, 75, 81, 87, 100, 112, 118, 125, 132, 140, 150, 156, 162, 175, 181, 187, 200). Variable-ratio values of 50 and 25 were used for some pigeons to maintain responding without pauses after attempts with VR 100 failed to do so consistently.

*Key-peck maintenance and extinction.* The experiment consisted of repeated exposures to a three-phase series. In the first phase, reinforcers were arranged according to a multiple VR *n* VR *n* schedule (multiple VR VR). When performance was stable (see below), the second phase was implemented using a multiple VR *n* FR 1 schedule of reinforcement (multiple VR FR 1). For the majority of the assessments, the multiple VR FR 1 phase continued until a predetermined number of reinforcers was delivered. The multiple VR FR 1 phases for Pigeon 2374 (Series 1 and 2), Pigeon 3519 (Series 1 and 2), and Pigeon 3180 (Series 1) were terminated when performances stabilized as defined below. The third phase consisted of a multiple extinction extinction (multiple EXT EXT) schedule and was terminated after no key pecking occurred for five consecutive daily sessions. Table 2 shows the number of sessions for each phase of each series and the total number of reinforcers for the multiple VR VR and multiple VR FR 1 phases. The numbers listed below each pigeon's identification number indicate the order of exposure (i.e., the pigeon was exposed to Number 1 first, followed by Number 2, etc.). Note that Pigeons 3180 and 3519 in Extinction Series 6 and 7, respectively, were exposed to the multiple EXT EXT phase immediately after the multiple VR VR phase. Due to experimental error (accidental exposure to multiple VR VR or multiple VR FR 1 schedules during extinction), multiple EXT EXT phases for 2842-2, 3180-3, 3519-2, 3, 4, and 6 were not continued to the extinction criterion. An equipment failure caused a dimmer green keylight to be presented during the multiple VR FR 1 and multiple EXT EXT portions for 2 pigeons. This keylight stimulus change occurred for Pigeons 2880-1 and 3519-4 (13 and 24 sessions, respectively) before the introduction of the multiple EXT EXT sched-

ule. The data for pigeons exposed to experimental errors are presented for the individual pigeons but are not included in the group analyses.

The scheduled duration of each presentation of a component during multiple EXT EXT (Appendix A) was calculated in the following ways. A geometric mean of the duration of each individual component was calculated from the last five sessions under the VR schedule in that component. For some of the series (Pigeons 3519-1, 2, 3; 3180-1, 2; 2875-1; 2374-1, 2), the individual geometric means for each of the components were then used to time the individual component presentations during extinction, resulting in a separate value for each of the green and red keylight components (e.g., eight different values for subjects exposed to eight components). For other series (Pigeons 2880-1; 2875-2; 2822-1), all the component durations during extinction were the same length for all the green and all the red keylight components (i.e., one value for all of the green keylight components and another value for all of the red keylight components) and were based on the arithmetic average of VR component durations in the last five sessions before extinction. In the remaining series, the longer of the two arithmetic means of the component durations was used for all components during extinction, resulting in one value used to time the durations of all the components for both the green and red keylight components. One important result of how component durations were arranged is that in all multiple EXT EXT phases (except for Pigeon 2374-1), the two stimuli of the multiple schedule were presented for equal durations, or the stimulus previously paired with FR 1 was presented for a longer duration. Instances of longer exposure to the stimulus previously associated with FR 1 during extinction therefore should provide a conservative estimation of the PREE.

*Key-peck retraining.* Once responding met an extinction criterion during the multiple EXT EXT schedule (i.e., 5 successive days without a response in the presence of either stimulus), the pigeon was exposed to a multiple FR 1 FR 1 schedule during the following daily session. The multiple VR VR schedule was gradually reinstated in a series of steps, as designated in Table 1. Retraining consisted of in-

Table 2  
Session and reinforcer presentation parameters and total responses during extinction.

Pigeon and extinction series	Number of sessions			Total reinforcers per component		Extinction responses after	
	Multiple VR VR	Multiple VR FR 1	Multiple EXT EXT	Multiple VR VR	Multiple VR FR 1	VR	FR 1
2374							
1	54	130	27	1,350	3,250	4,767	1,805
2	38	62	45	950	1,550	1,814	1,223
2822							
1	11	29	72	220	580	11,763	10,927
2	30	1	98	600	20	5,222	5,056
2842							
1	61	45	31	1,220	900	2,979	1,952
2 <sup>a</sup>	38	101	15	760	2,020	1,809	1,371
3	22	150	31	440	3,000	2,447	532
4	30	2	77	600	40	1,859	1,896
2875							
1	77	29	18	1,540	580	3,470	2,129
2	8	125	44	160	2,500	3,622	1,310
3	30	1	69	600	20	1,453	2,823
2880							
1 <sup>b</sup>	124	91	10	2,480	1,820	3,335	417
2	29	11	37	580	220	4,419	3,145
3	90	63	33	1,800	1,260	4,398	2,973
3180							
1	260	90	42	6,500	2,250	10,371	5,202
2	72	23	54	1,800	575	14,267	9,372
3 <sup>a</sup>	69	79	30	1,725	1,975	20,010	9,044
4	24	49	51	600	1,225	10,275	8,535
5	18	1	63	450	25	8,899	7,358
6	30	0	42	750	0	4,331	3,193
3519							
1	40	50	26	1,000	1,250	7,292	5,321
2 <sup>a</sup>	50	12	30	1,250	300	5,816	4,185
3 <sup>a</sup>	17	129	48	425	3,225	4,608	1,841
4 <sup>a,b</sup>	19	90	34	475	2,250	3,400	1,933
5	14	49	32	350	1,225	3,642	1,987
6 <sup>a</sup>	7	1	25	175	25	2,979	1,708
7	15	0	72	375	0	3,251	2,987

<sup>a</sup> Did not meet five-session linked extinction criteria.

<sup>b</sup> Change in green keylight in multiple VR FR 1 phase.

creasing both VR schedules (e.g., FR 1, VR 2, VR 5, VR 10, VR 20, VR 50, VR 75, VR 100) when the daily cumulative records showed consistent responding without pauses.

If a pigeon did not peck within approximately 5 min after the beginning of the multiple FR 1 FR 1 session, one of two priming procedures was used to generate responding. The first procedure consisted of operating the food hopper once or twice for 3 s independent of responding. The second procedure consisted of the experimenter opening

the chamber door and pressing the lighted center key with his finger, which operated the feeder. A few pigeons began key pecking within the first 5 min of the multiple FR 1 FR 1 schedule, and the rest of the pigeons began key pecking after one of the two priming procedures.

*Statistical procedures.* At some points in the experiment, stability criteria were employed to determine when to change phases. Stability criteria were calculated using kappa (Johnston & Pennypacker, 1980) and celeration

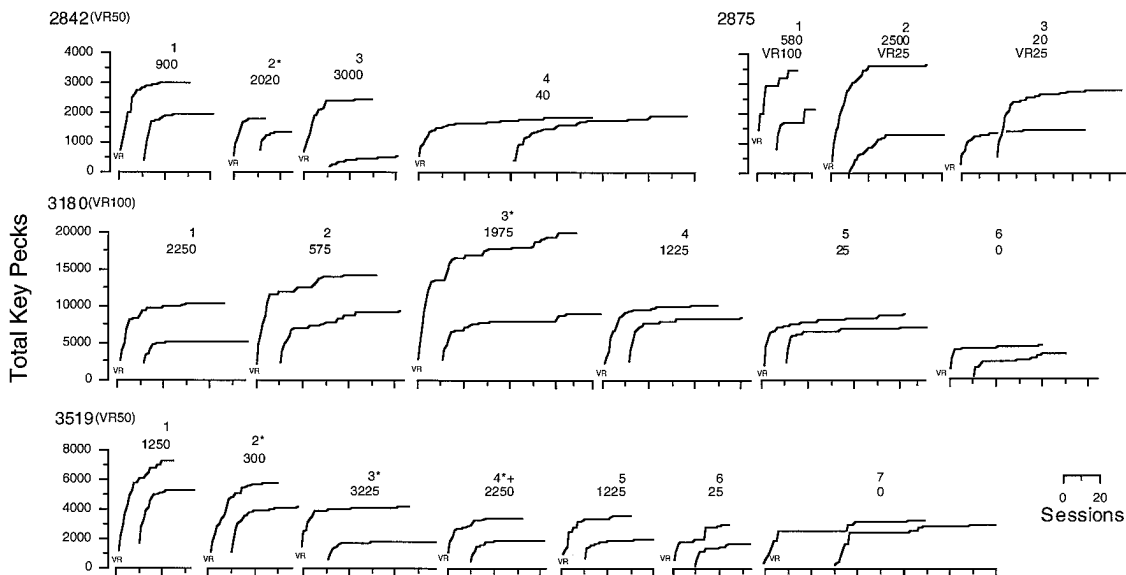


Fig. 1. Cumulative responses in extinction over sessions for Pigeons 2842, 2875, 3180, and 3519. Each curve begins with the total number of responses emitted during the component for the first session. The left curve of each pair is from the component associated most recently with VR, and the right curve of each pair is from the component recently associated with FR 1. Note that the vertical axes change across pigeons. The number above and to the left of each pair of curves indicates the order in which the extinction series was presented for each pigeon. Below these numbers are the number of reinforcers per component delivered during multiple VR FR 1. Next to each pigeon number (above the y axis) is the value of the VR schedule used during the multiple VR VR and multiple VR FR 1 phases of the individual extinction series. For Pigeon 2875 the VR value used in each series is located below the value for the number of reinforcers. The asterisks designate the termination of the extinction phase before reaching the extinction criterion (i.e., five consecutive sessions without a response in either component). The plus sign (3519-4) designates an apparatus failure (see text) during multiple VR FR 1 of the extinction series.

(Lindsley, 1969; cited by Johnston & Pennyacker, 1980). Stability was defined arbitrarily as celeration values between 0.90 and 1.10 and kappa values less than or equal to 1.10 for each component (green or red) of the multiple schedule and were based on the response rates for each component during the five most recent consecutive daily sessions. The geometric mean ratio (GMR) measured the equality of responding between the two VR components (multiple VR VR phase) and was computed as the ratio of the geometric means of the response rates for the last five sessions for each component, the larger geometric mean divided by the smaller. Equivalence between components was defined as a GMR value less than or equal to 1.10.

For the last series replication for Pigeons 2822, 2842, 3875, 2880, and 3180, changes from the multiple VR VR to the multiple VR FR 1 schedule occurred after approximately 30 sessions independent of the stability criteria. Due to the focus of the experiment on

the manipulation of the number of reinforcers delivered during multiple VR FR 1, only five of the changes to multiple EXT EXT were made with regard to the stability criteria (2374-1, 2; 3519-1, 2; and 3180-1). The remaining changes from multiple VR FR 1 to multiple EXT EXT were determined arbitrarily and were chosen to examine representative values of the number-of-reinforcers parameter.

## RESULTS

In 23 of 25 cases, there were fewer total responses during extinction after a recent FR 1 history than after a VR history (see Table 2, last two columns). Figure 1 shows cumulative extinction curves for Pigeons 2842, 2875, 3180, and 3519. For the first few sessions of extinction there was a high rate of responding after both FR 1 and VR schedules. The VR history generally produced a high rate of responding during extinction for

a few additional sessions before response rates decreased. Major changes in key-pecking rates (i.e., responses in only one of the components) generally were not seen after the first 10 to 15 sessions of extinction. Cumulative responses during extinction after FR 1 occasionally exceeded cumulative responses after VR, but this reversal only resulted in a reversed PREE on only two occasions (i.e., 2875-3 and 2842-4), both after minimal FR 1 training.

Figure 2 shows scatter plots of the number of key pecks emitted during extinction in the presence of the stimulus that had been correlated with VR reinforcement (upper left panel) and with FR 1 (upper right panel) as a function of the number of reinforcers per schedule component presented during the preceding multiple VR FR 1 phase. The lower left panel shows key pecks in extinction during the stimulus that was formerly correlated with a VR schedule as a function of the number of reinforcers per component schedule during both the multiple VR VR and multiple VR FR 1 phases. These analyses show both between- and within-subject variation. The number of responses emitted during extinction in the presence of the stimulus that had been correlated with FR 1 was variable across subjects ( $r = -.31$ ). Pigeons 3180 and 3519 showed no systematic effect of the number of reinforcers delivered during the immediately previous multiple VR FR 1 phase, whereas Pigeons 2842 and 2875 showed decreases in the number of responses during extinction as the number of previous reinforcers during the multiple VR FR 1 schedule increased. The number of responses emitted during extinction after VR reinforcement also was variable across subjects and showed no systematic relation ( $r = -.03$ ) to the number of reinforcers per component schedule presented during the multiple VR FR 1 schedule, or to the number of reinforcers per component presented during the multiple VR VR and multiple VR FR 1 phases combined ( $r = .22$ ; this value is inflated by the rightmost point).

Figure 3 shows an extinction ratio as a function of the number of reinforcers per component schedule presented during the immediately preceding multiple VR FR 1 phase. The extinction ratio compares responding during the two discriminative stimuli by dividing the total responses emitted

during extinction in the presence of the VR discriminative stimulus by the total number of responses emitted during extinction in the presence of the FR 1 discriminative stimulus. An extinction ratio of 1.00 indicates no difference between the extinction performances after VR and FR 1 (dotted horizontal line). Extinction ratios greater than 1.00 indicate a PREE. Ratios less than 1.00 indicate a reversed PREE. The larger the absolute value of the extinction ratio, the greater the differences in extinction performances after VR and FR 1. The extinction ratio was almost always greater than 1.00 and usually increased as the number of reinforcers during multiple VR FR 1 increased ( $b$  [slope] = .71,  $r = .83$ ) for the combined data. The dashed lines for Pigeons 3180 and 3519 show the ratio following multiple VR VR (no interpolated FR 1) and thus provide an estimate of color bias. For both pigeons there was a bias toward the color that was consistently associated with the VR schedule. The estimate of color bias was made in the last condition for these 2 subjects (Table 2).

Several extinction criteria were used post hoc to determine the relation between time-without-a-response extinction criteria and the PREE. Each criterion required a continuous period of time without a response (i.e., five sessions, one session, or one component). In addition, these criteria could be linked to both discriminative stimuli of the multiple-schedule pair. For example, a linked criterion stipulated that a response could not occur for five consecutive sessions in the presence of either stimulus of the multiple schedule. An unlinked criterion was the termination of the extinction phase for each stimulus separately. Thus, once an extinction criterion was met in the presence of one stimulus of a two-component multiple schedule, responses were no longer counted for that stimulus, but responses in the presence of the other stimulus continued to be counted until the extinction criterion was met for that stimulus. Figure 4 shows that the more stringent the extinction criterion (i.e., longer time without a response and linked to both discriminative stimuli), the larger the correlation between the extinction ratio and the number of reinforcers delivered during the previous VR FR 1 phase. Pearson  $r$  values for the regression line fit to the extinction ratio data decreased monoton-

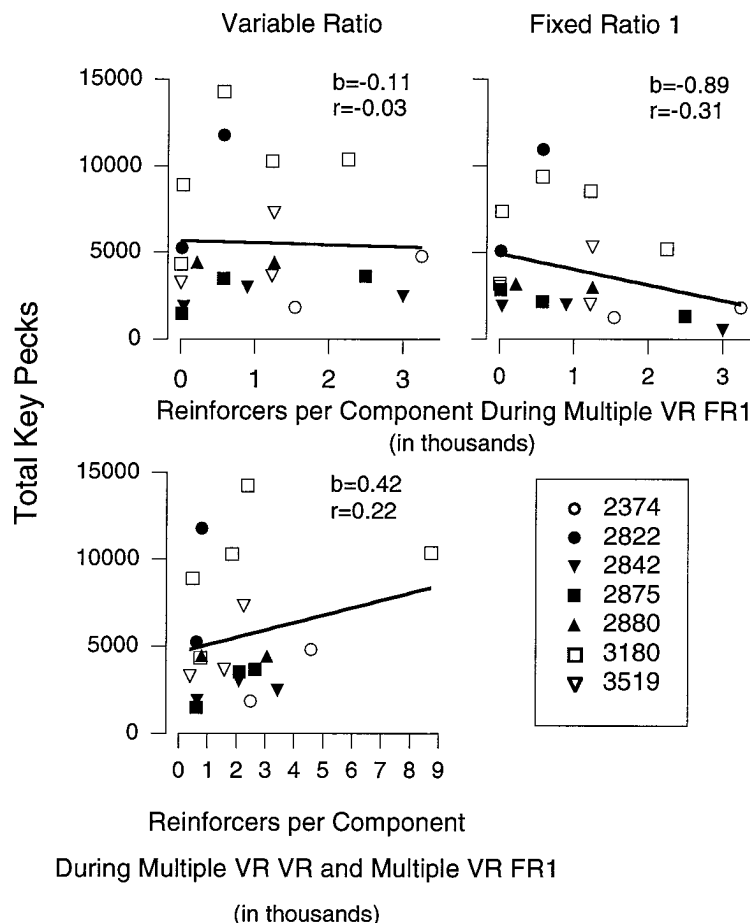


Fig. 2. Total number of key pecks in extinction after VR reinforcement (upper left panel) and total number of responses during extinction after FR 1 (upper right panel) for each extinction series as a function of the number of reinforcers per component schedule during the multiple VR FR 1 schedule. The lower left panel shows the total number of key pecks in extinction after VR reinforcement as a function of number of reinforcers per component schedule during both the multiple VR VR and multiple VR FR 1 phases. Each panel shows the data points for all extinction series except those that did not meet the extinction criterion and those that followed an apparatus failure during multiple VR FR 1. "r" is Pearson's  $r$  and "b" is the slope of the regression line (method of least squares) fit to all the points.

ically in relation to the stringency of the extinction criterion. The slope of the regression line also decreased, but not as consistently.

Figure 5 shows scatter plots of the total number of key pecks emitted in the presence of each discriminative stimulus of the extinction phase and the extinction ratio, plotted as a function of the order of the extinction series, to examine the effect of repeated exposure to extinction. Data for all subjects were combined to calculate the correlation between repeated exposure to extinction and the three measures described above. Total re-

sponses (FR 1,  $r = -.08$ , VR,  $r = -.20$ ) and extinction ratio ( $r = -.18$ ) measures showed no consistent relation to the number of exposures to extinction.

Extinction performances also were measured in terms of the changes in the log proportions of the response rates of the first extinction session (cf. Nevin, Smith, & Roberts, 1987) over the first 10 sessions of multiple EXT EXT. Response rates generated in the VR component of the multiple VR FR 1 were usually higher than response rates in the FR 1 component. Proportion of initial extinction



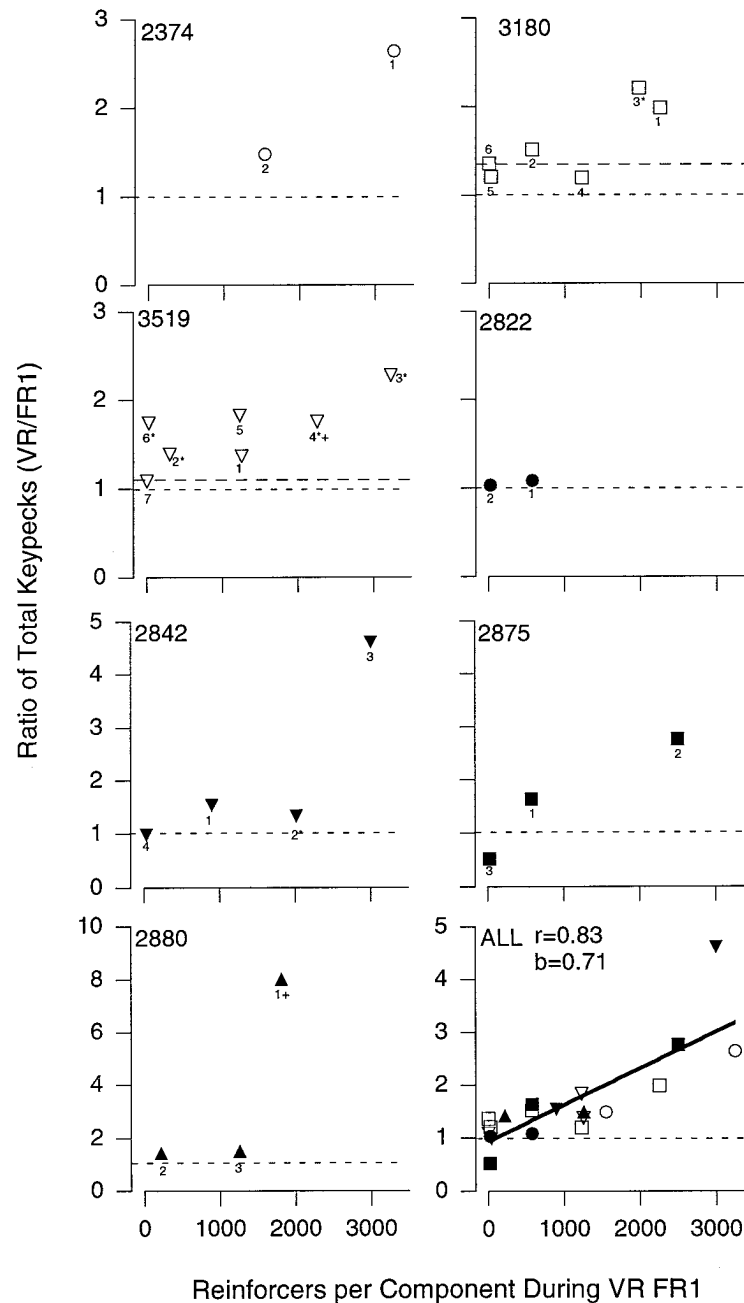


Fig. 3. Total responses during extinction expressed as the extinction ratio (VR responses:FR 1 responses; vertical axes) for each extinction series as a function of the number of reinforcers per component schedule during the immediately preceding exposure to multiple VR FR 1 (horizontal axes) for each pigeon. The dashed lines for Pigeons 3519 and 3180 show the extinction ratio after exposure to the multiple VR VR phase only. Asterisks designate the termination of the extinction phase before reaching the extinction criterion. Plus signs designate an apparatus failure during the multiple VR FR 1 phase of the extinction series. The panel labeled "ALL" shows the data points from the individual plots except those that did not meet the extinction criterion and those that followed the apparatus failure during multiple VR FR 1. "r" is Pearson's  $r$  and "b" is the slope of the regression line fit to all the points in the graph.

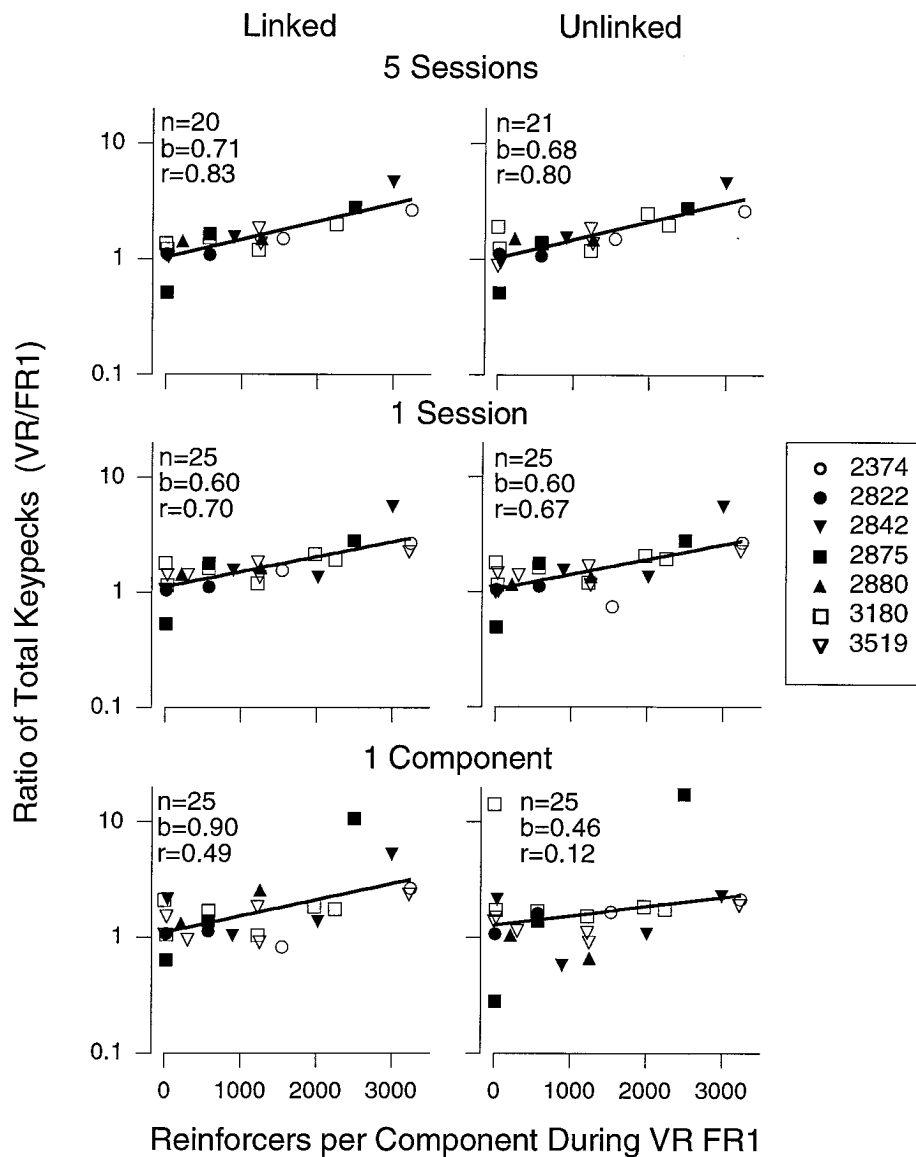


Fig. 4. Total number of key pecks during extinction expressed as the extinction ratio (vertical axes) for each extinction series as a function of the number of reinforcers per component schedule during the prior multiple VR FR 1 schedule (horizontal axes) for several extinction criteria. "5 sessions" indicates five consecutive sessions without a key peck, "1 session" indicates one session without a key peck, and "1 component" indicates one component without a key peck. " $r$ " is Pearson's  $r$ , " $b$ " is the slope of the regression line, and " $n$ " equals the number of extinction series that met the extinction criterion.

responding was used to adjust for these initial differences produced by the different schedules of reinforcement. The slopes, calculated using the method of least squares, provided an index of the rate of change from the baseline conditions. The smaller the value of the slope ( $b$ ), the greater the resistance to extinc-

tion (behavioral momentum). This relation between the slope measure and behavioral momentum required the ratio of the slopes to be expressed as slope FR 1 divided by slope VR to make it comparable to the extinction ratio (see above). A ratio of slopes of 1.00 indicates no PREE. Values greater than 1.00

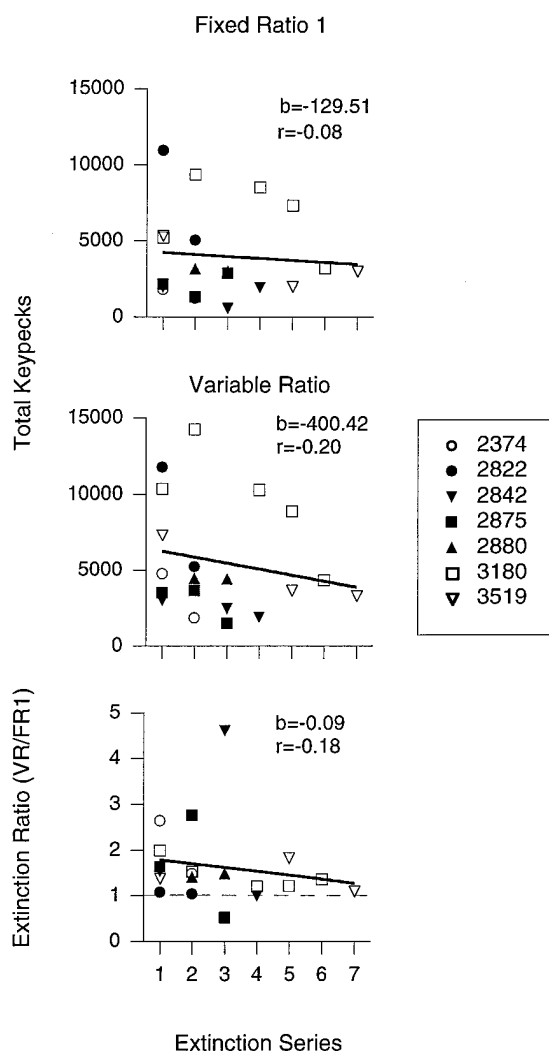


Fig. 5. Total number of key pecks in extinction after FR 1 (upper panel) and total number of key pecks in extinction after VR reinforcement (middle panel) as a function of the presentation order of the extinction series. The lower panel shows the extinction ratio (total responses in the former VR component:total responses in the former FR 1 component) as a function of the presentation order of the extinction series. The dashed line at 1 on the vertical axes designates no PREE. Each panel shows the data points for all extinction series except those in which the extinction criterion was not met and those that followed an apparatus failure during multiple VR FR 1. "r" is Pearson's  $r$  and "b" is the slope of the regression line fit to all the points.

indicate a PREE, and values less than 1.00 indicate a reversed PREE. Figure 6 shows the linear regression lines fitted to the log proportion data for 2 pigeons. Pigeons 3519-1 and 2842-4 provide examples of the PREE

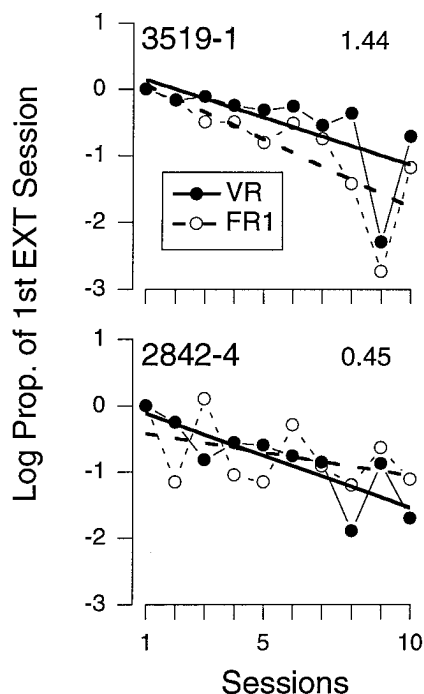


Fig. 6. Individual extinction performances (3519-1 and 2842-4) expressed as the log proportion of key pecks per minute during the first extinction session across the following nine sessions of the extinction phase (horizontal axes). Closed circles represent extinction performances after VR. Open circles represent extinction performances after FR 1. Regression lines were fit by the method of least squares. Heavy solid lines represent the slope of the log proportions after VR, and dashed lines represent the slope of the log proportions after FR 1. The number in the upper right of each panel is the value of the ratio of the slopes (FR 1:VR).

and the reversed PREE, respectively. Included in each panel is the value for the ratio of slopes.

Ratios of slopes for the log proportion data were calculated for all series, and Figure 7 shows scatter plots of the ratios of the slopes as a function of the number of reinforcers delivered during multiple VR FR 1. Data from all the pigeons were included, except those from Pigeons 2880-1 and 3519-4 due to the apparatus failure during multiple VR FR 1. The ratios of the slopes of the log proportions were uncorrelated with the number of reinforcers per component delivered during the multiple VR FR 1 phase ( $r = -.01$ ), but the between-subjects variability in the ratios seemed to decrease as the number of reinforcers per component schedule during mul-

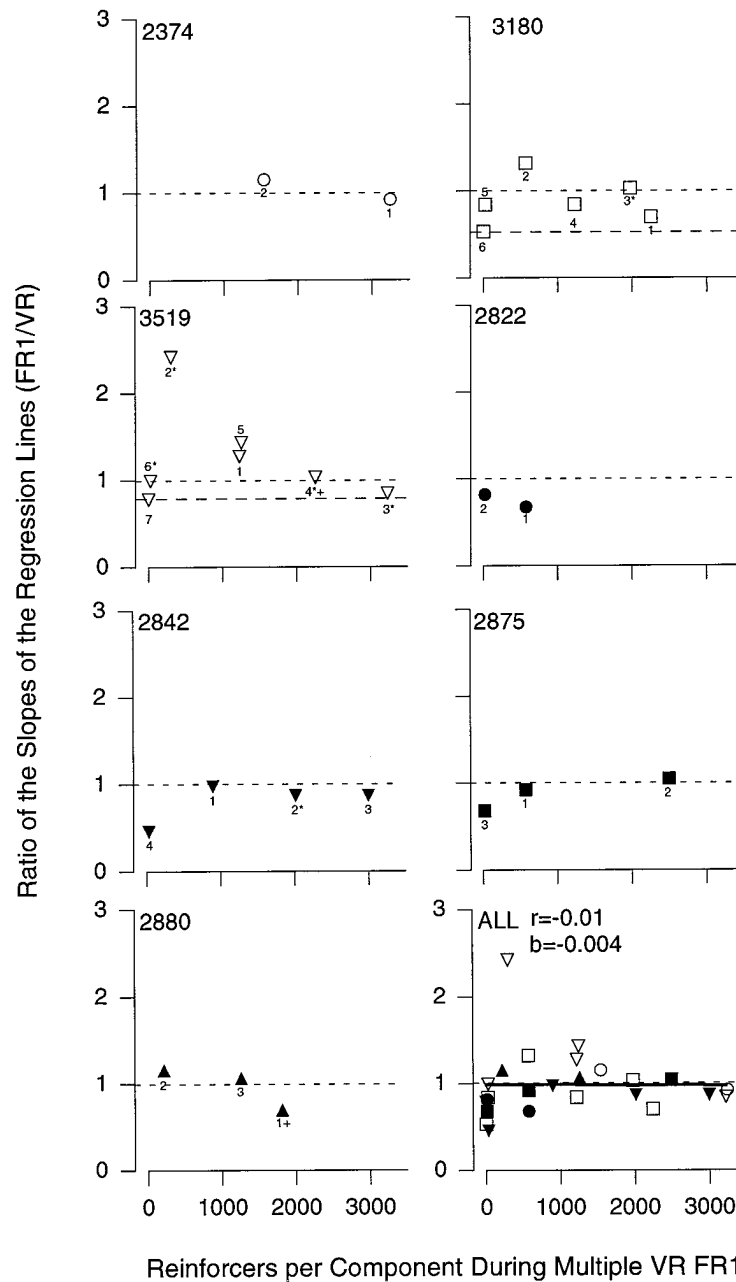


Fig. 7. Rate of key pecking during the first 10 sessions of extinction expressed as the extinction ratio (FR 1:VR) for slopes of the log proportions as a function of the number of reinforcers per component schedule during the immediately preceding exposure to a multiple VR FR 1 schedule (see text for additional explanation). The dashed line for Pigeons 3519 and 3180 highlights the slope extinction ratio after exposure to the multiple VR VR phase only. Values greater than 1 indicate a PREE. Values less than 1 indicate a reversed PREE. The bottom right graph shows data for all subjects combined. The solid dark line was fit by the method of least squares, and regression parameters are indicated.

title VR FR 1 increased. When the data were viewed as a proportion of response rate during the initial extinction session, there was no consistent evidence of either a PREE or a reversed PREE over the first 10 sessions of extinction.

### DISCUSSION

The PREE, as measured by the total number of responses during extinction, was replicated both within and between subjects using a within-subject free-operant experimental design. The PREE was evident across a range of VR values and session durations as well as different numbers of interpolated reinforcers delivered with an FR 1 schedule. These data conflict with the reversed PREEs generated by previous free-operant within-subject experiments (Adams et al., 1982; Pavlik & Carlton, 1965; Pavlik et al., 1967).

The difference in results between the present and previous reports may have been due to our equating the number of reinforcers delivered during both the FR 1 and VR schedules. Equating the number of reinforcers in between-subjects experiments has not been necessary to produce the PREE (see Jenkins & Stanley, 1950). The extent to which the PREE can be produced using a within-subject procedure without equating the number of reinforcers presented during the intermittent reinforcement and FR 1 schedules, however, has not been examined explicitly. An experiment relevant to this issue (Pavlik, Carlton, & Manto, 1965) compared a within-subject procedure that equated the number of responses (60) to a procedure that equated the number of reinforcers (40). Both procedures produced a PREE, but equating the number of reinforcers produced a larger PREE as estimated by the difference in the total extinction responses. Although it may not be necessary, equating the number of reinforcers between intermittent reinforcement and FR 1 schedules may increase the likelihood of producing a within-subject PREE.

In the present study, the number of responses emitted during extinction showed no consistent relation to the number of reinforcers presented during training, which conflicts with previous experiments (Hearst, 1961; Jenkins, 1962; Perin, 1942; Williams, 1938; Wilson, 1954). This failure to replicate the con-

ventional relation between number of reinforcers and number of responses in extinction may be a result of the extensive amount of training involved in the present experiment. The numbers of reinforcers delivered before extinction was implemented in the present procedure were for the most part far in excess of those used in previous research on extinction. Experiments in which the number of reinforcers has been manipulated did not exceed 100 reinforcers during training (Hearst, 1961; Jenkins, 1962; Perin, 1942; but see Wilson, 1954).

The extent to which additional reinforcement training will increase responding during extinction may be limited. In effect, a ceiling may be reached whereupon responding during extinction would no longer increase with additional reinforcement during training. Previous experiments that manipulated the number of reinforcers (Hearst, 1961; Perin, 1942; Williams, 1938) have examined smaller ranges and have shown that the relation between number of reinforcers and extinction responses is not simply linear, but is more accurately described by a negatively accelerated function that approaches an asymptote. The nature of this function may explain why the present experiment did not reveal a consistent relation between number of reinforcers and number of extinction responses. In the presence of the stimulus that was correlated with VR reinforcement throughout the first two phases of the extinction series, the number of reinforcer presentations ranged from 200 to 8,750, which may be at the high end of a negatively accelerating function. If so, the lack of a relation between reinforcers in the presence of the VR discriminative stimulus and the number of responses in extinction after VR reinforcement would be understandable.

The use of a conservative extinction criterion (five sessions without a response in the presence of either discriminative stimulus) in the present study made it possible to compare several criteria, retrospectively, that were less conservative. The correlation between the extinction ratio and the number of reinforcers presented during training decreased as the criterion was made more lenient (i.e., less continuous time without a response). Independent (i.e., unlinked) determination of extinction for the discriminative stimuli also

reduced the Pearson  $r$  values. These results suggest that part of the variability reported by Williams (1938), Perin (1942), and others may have been due to the premature termination of the extinction procedure. Until there is a more thorough analysis of the role that extinction criteria play in the production of the PREE, criteria based on time without a response should be fairly conservative and should be tied to extinction after both FR 1 and intermittent reinforcement to equate the total amount of exposure to extinction.

One concern with individual-organism phenomena is the repeatability of the event within a single subject. Does the experience of a certain kind leave the organism irreversibly changed with respect to that kind of experience from that point forward? Previous research (Bullock & Smith, 1953; Clark & Taylor, 1960) suggested that extinction had an irreversible effect upon an organism. Repeated exposure to FR 1 followed by 60 or 90 min of extinction reduced the number of lever presses over successive extinction tests (i.e., the repeated-extinction effect) when both training and extinction occurred on the same day. Repeated exposure to intermittent reinforcement followed by extinction also showed the repeated-extinction effect (Bullock, 1960). When rats were exposed to FR 1 and extinction on alternate days, the number of bar presses increased during the second exposure to extinction but slowly decreased during successive replications (Wickens & Miles, 1954). The repeated-extinction effect, however, was not found when the cycle consisted of a training phase of 2 days followed by an extinction phase of 8 days (Anger & Anger, 1976) unless the analysis was limited to the first session of each eight-session extinction condition. These results suggest that responding early in extinction may be reduced over successive exposures to extinction, but overall output during extinction is not diminished. Use of the stringent criterion of extinction employed in the present experiment may have made it less likely that a repeated-extinction effect was observed. Consistent with this view is that the total number of responses emitted during the first session of an extinction block (normalized by expressing the first-session totals for all subsequent extinction exposures as proportions of the first-session total from the first exposure to

extinction) was negatively correlated with the number of exposures to extinction ( $r = -.46$  after VR,  $r = -.53$  after FR 1). The present findings, in combination with those from previous research, indicate that virtually complete extinction of behavior may be a reversible process, at least with respect to total responses emitted, if the organism is presented with enough reinforcers between extinction exposures and responding is allowed to occur until extinction is essentially complete.

In the present experiment, exposing individual subjects to both VR and FR 1 histories of reinforcement may have produced an interaction between the two schedules of reinforcement (e.g., chaining). To reduce possible conditioning effects produced by the presentation of the FR 1 component, the key-light and houselight were darkened for 1 min between the components. The darkened key was operated (topography unknown) on occasion (i.e., about once or twice every 10 sessions), but the lack of continued and persistent responding during the 1-min timeout intervals is inconsistent with the view that chained responding between the VR and FR 1 components occurred during the multiple VR FR 1 phase.

Multiple schedules also may result in behavioral contrast or induction interactions. These types of interactions occur when changing reinforcement rate in one component of the multiple schedule affects the rate of responding in the other component. In the case of behavioral contrast, the effect is in the opposite direction of the change in reinforcement rate (e.g., decreasing rate of reinforcement in one component increases the rate of responding in the other component). In behavioral induction, the change in response rate is in the same direction as the change in reinforcement rate (e.g., decreasing the rate of reinforcement in one component decreases the rate of responding in the other component). These types of interaction could be detected when schedules were changed from multiple VR VR to multiple VR FR 1. Changing one component from VR to FR 1 increased the rate of reinforcement for that component. The effect of this change on the terminal performance of the unchanged component (e.g., 5 days before the initiation of the multiple EXT EXT phase) was inconsistent. Pigeons 2374 and

2822 showed consistent increases, and Pigeon 2880 showed consistent decreases in key-pecking rates in the unchanged component, but most showed varied effects (3519, 2875, 3180, and 2842). The lack of a consistent contrast or induction effect both between and within subjects suggests that this variable had little influence on extinction responding under the present parameters.

A possible limitation of the multiple-schedule design centers on the choice of the key-light color of the first component of the first extinction session. Discriminative stimuli that occasioned the different reinforcement schedules (i.e., VR or FR 1) were presented at different times during training and continued to be presented at different times during extinction. This procedure requires each subject to be exposed to extinction in the presence of one discriminative stimulus before being exposed to extinction in the presence of the other discriminative stimulus. The arrangement gave each subject an immediate history with extinction, in the presence of the first discriminative stimulus, that could have reduced the number of responses in the presence of the second discriminative stimulus. To investigate this possibility, the data from all the pigeons in this experiment were grouped together for a post hoc statistical analysis. Two analyses of variance for repeated measures were calculated to examine the effect the order of discriminative stimulus presentations might have had on (a) the total number of responses emitted during the first two discriminative stimulus presentations and (b) those emitted during the entire extinction phase. Results from the first analysis showed a statistically significant interaction effect between the order of the first two discriminative stimuli and the total number of responses emitted during those components,  $F(1, 24) = 4.45, p < .05$ . That is, the total number of responses in the presence of the discriminative stimulus associated with VR reinforcement was higher when it was presented first than when it was presented second. The total number of responses in the presence of the discriminative stimulus associated with FR 1 reinforcement, however, was not consistently higher or lower whether that discriminative stimulus had been presented first or second. Analysis of the entire extinction phase (i.e., to the extinction criterion)

showed no statistically significant effects. These results suggest that the order of component presentation may be important early in extinction, but that the effect is reduced with continued exposure to alternating extinction components.

The present experiments were not specifically designed to test extant theories of the PREE, and the results generally have little bearing on them. The results may, however, have relevance for Nevin's approach based on the concept of behavioral momentum (see Nevin, 1988). In its simplest form, Nevin's account predicts more resistance to change as rate of reinforcement in the presence of a stimulus prior to extinction is increased. In general, change during extinction is measured as a proportional change in rate over the course of extinction. To assess the rate of change, straight-line functions can be fit to proportions (or logarithms) of rates over the course of extinction. Greater resistance is indicated by shallower slopes. The conditions of the present study, therefore, would be predicted to produce shallower slopes for extinction after FR 1 because rate of reinforcement is higher under FR 1 than under the VR schedules. Such a result was not consistently obtained (see Figures 6 and 7).

The findings of our study stand in contrast to those described by Nevin (1988) in his review of several studies in which FR 1 and intermittent reinforcement were compared. He found that slopes for responding after FR 1 training were shallower than those for responding that had been maintained by intermittent reinforcement, and that the difference in slopes increased as the number of reinforcers during training increased from 15 to 500. Total numbers of reinforcers during training, especially if considered across the duration of the experiments, were much greater in our study, and the differences in results may be related to this factor.

Although the present study does not offer much information relevant to several theories of the PREE, with some modification the technique used here could be applied to test those theories. For example, the discrimination hypothesis put forth by Mowrer and Jones (1945) could be examined by having several, rather than two, components in the multiple schedule. The degree of similarity between extinction and conditions of rein-

forcement (the factor suggested by Mowrer and Jones to be the determinant of the PREE) could then be varied systematically across components. Such a procedure might also serve to test Capaldi's sequential theory (Capaldi, 1967) by arranging particular sequences of reinforced and unreinforced responses in different components of the multiple schedule.

The present experiment illustrates a procedure for the repeated production of the PREE within a single organism. It seems safe to conclude from the results of the present experiment that the PREE is a behavioral phenomenon (Sidman, 1960) that exists at the level of individual organisms. The present procedure can therefore be used to assess a range of parameters of a variety of independent variables on a continuous measure of the magnitude of the PREE (i.e., the extinction ratio). For example, the present experimental procedure could be used to assess more accurately the effects of repeated exposures to extinction. If the repeated-extinction effect is constant (i.e., the extinction ratio remains unchanged after repeated exposure to the same number of reinforcers during training), a baseline would then exist to test a range of independent variables on behavior undergoing extinction using a single organism.

## REFERENCES

- Adams, J. F., Nemeth, R. V., & Pavlik, W. B. (1982). Between- and within-subjects PRE with sucrose incentives. *Bulletin of the Psychonomic Society*, 20, 261-262.
- Anger, D., & Anger, K. (1976). Behavioral changes during repeated eight-day extinctions. *Journal of the Experimental Analysis of Behavior*, 26, 181.
- Bullock, D. H. (1960). Repeated conditioning-extinction sessions as a function of the reinforcement schedule. *Journal of the Experimental Analysis of Behavior*, 3, 241-243.
- Bullock, D. H., & Smith, W. C. (1953). An effect of repeated conditioning-extinction upon operant strength. *Journal of Experimental Psychology*, 46, 349-352.
- Capaldi, E. J. (1967). A sequential hypothesis of instrumental learning. In K. Spence & J. T. Spence (Eds.), *The psychology of learning and motivation* (pp. 67-156). Academic Press, New York.
- Clark, F. C., & Taylor, B. W. (1960). Effects of repeated extinction of an operant on characteristics of extinction curves. *Psychological Reports*, 6, 226.
- Dyal, J. A., & Sytsma, D. (1976). Relative persistence as a function of order of reinforcement schedules. *Journal of Experimental Psychology: Animal Behavior Processes*, 2, 370-375.
- Gellermann, L. W. (1933). Chance orders of alternating stimuli in visual discrimination experiments. *Journal of Genetic Psychology*, 42, 206-208.
- Hearst, E. (1961). Resistance-to-extinction functions in the single organism. *Journal of the Experimental Analysis of Behavior*, 4, 133.
- Jenkins, H. M. (1962). Resistance to extinction when partial reinforcement is followed by regular reinforcement. *Journal of Experimental Psychology*, 64, 441-450.
- Jenkins, H. M., & Stanley, J. C. (1950). Partial reinforcement: A review and critique. *Psychological Bulletin*, 47, 193-234.
- Johnston, J. M., & Pennypacker, H. S. (1980). *Strategies and tactics of human behavioral research*. Hillsdale, NJ: Erlbaum.
- Likely, F. A. (1958). Relative resistance to extinction of aperiodic and continuous reinforcement separately and in combination. *Journal of General Psychology*, 58, 165-187.
- Mowrer, O. H., & Jones, H. (1945). Habit strength as a function of the pattern of reinforcement. *Journal of Experimental Psychology*, 35, 293-311.
- Nevin, J. A. (1988). Behavioral momentum and the partial reinforcement effect. *Psychological Bulletin*, 103, 44-56.
- Nevin, J. A., Mandell, C., & Atak, J. R. (1983). The analysis of behavioral momentum. *Journal of the Experimental Analysis of Behavior*, 39, 49-59.
- Nevin, J. A., Smith, L. D., & Roberts, J. (1987). Does contingent reinforcement strengthen operant behavior? *Journal of the Experimental Analysis of Behavior*, 48, 17-33.
- Pavlik, W. B., & Carlton, P. L. (1965). A reversed partial-reinforcement effect. *Journal of Experimental Psychology*, 70, 417-23.
- Pavlik, W. B., Carlton, P. L., Lehr, R., & Hendrickson, C. (1967). A reversed PRE. *Journal of Experimental Psychology*, 75, 274-276.
- Pavlik, W. B., Carlton, P. L., & Manto, P. G. (1965). A further study of the partial reinforcement effect with subjects. *Psychonomic Science*, 3, 533-534.
- Perin, C. T. (1942). Behavior potentiality as a joint function of the amount of training and the degree of hunger at the time of extinction. *Journal of Experimental Psychology*, 30, 93-113.
- Quartermain, D., & Vaughan, G. M. (1961). Effect of interpolating continuous reinforcement between partial training and extinction. *Psychological Reports*, 8, 235-237.
- Sidman, M. (1960). *Tactics of scientific research: Evaluating experimental data in psychology*. New York: Basic Books.
- Stalling, R. B., Moreland, J. W., Merrill, K. H., & Scotti, J. (1981). Continuous reinforcement interpolated between intermittent reinforcement and extinction decreases resistance to extinction. *Behavior Analysis Letters*, 1, 89-95.
- Sutherland, N. S., Mackintosh, N. J., & Wolfe, J. B. (1965). Extinction as a function of the order of partial and consistent reinforcement. *Journal of Experimental Psychology*, 69, 56-59.
- Theios, J. (1962). The partial reinforcement effect sustained through blocks of continuous reinforcement. *Journal of Experimental Psychology*, 64, 1-6.
- Walter, D. E., & Palya, W. L. (1984). An inexpensive ex-



- Received August 10, 1995  
Final acceptance September 9, 1996

Component durations (minutes) during extinction for each pigeon.

[illegible]

## APPENDIX B

Number of responses during extinction for each schedule up to the specified extinction criterion.

Pi- geon	Five-session unlinked		One session				One component			
			Linked		Unlinked		Linked		Unlinked	
	VR	FR 1	VR	FR 1	VR	FR 1	VR	FR 1	VR	FR 1
2374										
1	4,767	1,805	4,714	1,769	4,717	1,769	4,715	1,816	3,773	1,798
2	1,757	1,166	1,757	1,130	834	1,130	834	1,036	827	506
2822										
1	11,711	10,927	11,596	10,444	11,596	10,444	10,107	9,012	8,160	5,167
2	5,210	4,672	4,611	4,438	4,611	4,438	3,750	3,545	3,750	3,545
2842										
1	2,979	1,952	2,973	1,940	2,869	1,878	2,123	2,078	1,175	2,078
2	— <sup>a</sup>	— <sup>a</sup>	1,799	1,342	1,799	1,342	1,700	1,266	1,346	1,266
3	2,443	532	2,382	429	2,374	428	1,552	300	668	300
4	1,772	1,892	1,651	1,583	1,590	1,583	855	407	855	407
2875										
1	2,956	2,129	2,956	1,678	2,956	1,678	1,796	1,316	1,796	1,316
2	3,611	1,305	3,580	1,282	3,580	1,282	2,907	276	2,907	168
3	1,450	2,823	1,366	2,565	1,267	2,565	1,267	2,022	668	2,371
2880										
1 <sup>b</sup>	3,335	417	2,957	416	2,957	416	2,957	416	2,656	416
2	4,143	2,749	3,914	2,747	3,159	2,747	3,156	2,436	2,520	2,436
3	4,398	2,973	4,214	2,616	3,535	2,616	3,519	1,400	2,290	3,518
3180										
1	10,371	5,202	9,865	5,163	9,865	5,122	8,337	4,769	8,337	4,769
2	12,602	9,104	12,602	7,767	12,602	7,758	11,616	6,906	8,211	4,916
3	20,004	7,960	17,087	7,942	16,502	7,942	12,243	6,681	12,243	6,681
4	10,057	8,396	9,599	8,009	9,349	7,788	7,286	7,093	7,089	4,685
5	8,873	7,138	7,763	6,767	7,763	6,728	6,190	5,932	4,906	2,861
6	4,282	2,243	4,038	2,243	3,917	2,178	1,541	741	1,541	108
3519										
1	7,292	5,321	7,258	5,319	6,115	5,279	2,994	3,323	2,994	3,323
2	— <sup>a</sup>	— <sup>a</sup>	5,665	4,060	5,665	4,060	3,083	3,236	1,970	1,749
3	— <sup>a</sup>	— <sup>a</sup>	4,091	1,801	3,916	1,730	3,894	1,682	2,587	1,373
4 <sup>b</sup>	3,400	1,933	2,849	1,776	2,849	1,769	2,270	1,357	2,062	1,357
5	3,642	1,987	3,433	1,901	3,146	1,895	2,653	1,464	781	724
6	— <sup>a</sup>	— <sup>a</sup>	2,007	1,438	2,007	1,384	1,754	1,181	293	200
7	2,622	2,985	2,589	2,459	2,589	2,589	364	351	359	264

<sup>a</sup> Did not meet criterion.

<sup>b</sup> Change in green keylight in multiple VR FR 1 phase.